Plasma-Assisted Pre-Chamber Ignition System for Highly Dilute Stoichiometric Heavy-Duty Natural Gas Engines

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Annual Merit Review and Peer Evaluation Meeting

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Project ID: ace174

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Project Overview

Timeline

Project Start Date: 3/1/2022

Project End Date: 6/30/2025

Percent Complete: 5%

Budget

Total Project Funding:

DOE Share = $1,645,430

Contractor = $415,044

Barriers

Natural gas engine efficiency and emissions:

- Current NG engines must operate at stoichiometric to allow current low NOx emissions standards to be met with three-way catalyst aftertreatment
- Advanced ignition systems can allow high efficiency operation at high levels of dilution
- Pre-chamber and plasma ignition independently developed, but each have challenges alone

Partners

University of Minnesota

Sandia National Laboratories

Carnegie Mellon University, Pittsburgh Pennsylvania 1900

Relevance/Objectives

Overall Objectives

Research, develop, and validate a next generation heavy duty plasma-assisted pre-chamber ignition system equipped natural gas engine:

- Improve efficiency by ≥7% and achieving total ownership cost reduction of >6% when compared to the multi-cylinder baseline engine
- Use commercial three-way catalyst after treatment to achieve near zero (0.02 g/hp-hr NOx) emissions

Objectives in this Period

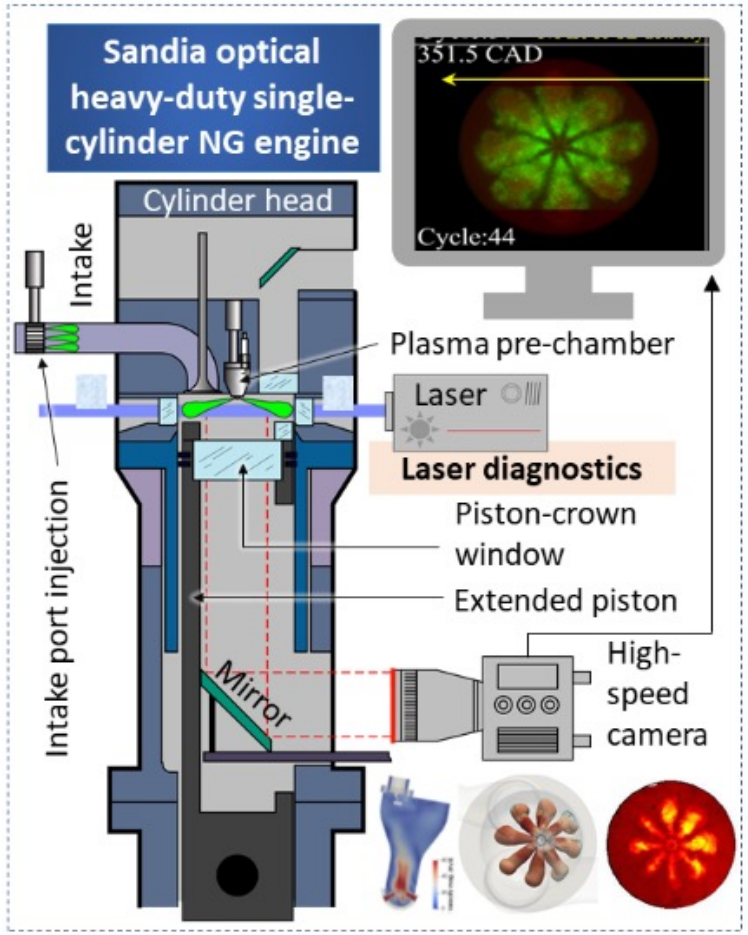
Construct baseline pre-chamber and plasma-assisted pre-chamber for comparison in experiments with a rapid compression and expansion machine and single cylinder optical engine

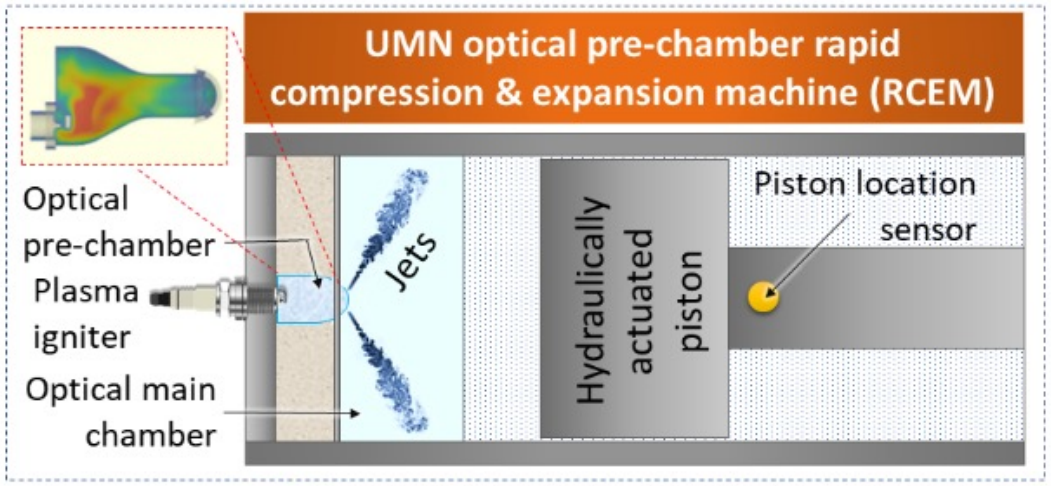
Milestones

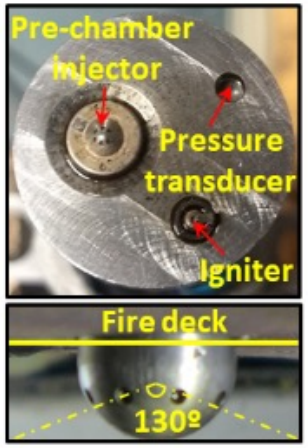
	BP 1					BP 2				BP 3			
	FY 22		FY 23			FY 24				FY 25			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
Budget Period 1: Construct and test baseline pre-chamber and plasma-assisted pre-chamber designs	M1.1	M1.2	M1.3	M1.4	D1.1								
Budget Period 2: Conduct fundamental optical engine and rapid compression and expansion machine experiments using plasma-assisted pre-chamber hardware						M2.1	M2.2	M2.3	D2.1				
Budget Period 3: Ignition system verified for performance and emissions targets. Advanced combustion modes studied										M3.1	M3.2	M3.3	M3.4
		Current											

Approach

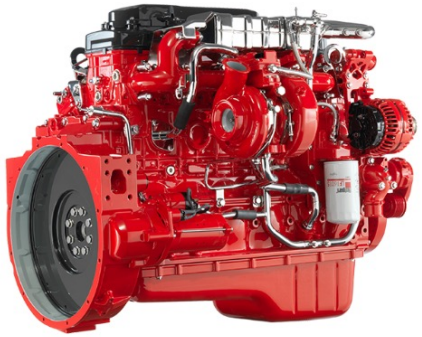
Transformative ignition system combines two existing technologies – plasma assisted igniters and pre-chamber combustion – to overcome the barriers of each single technology alone

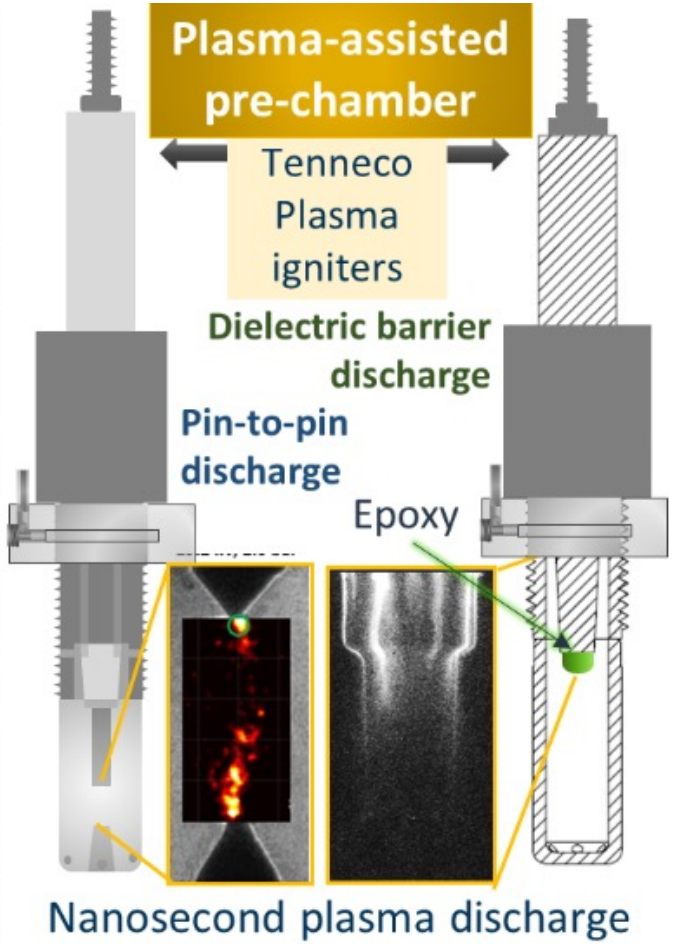






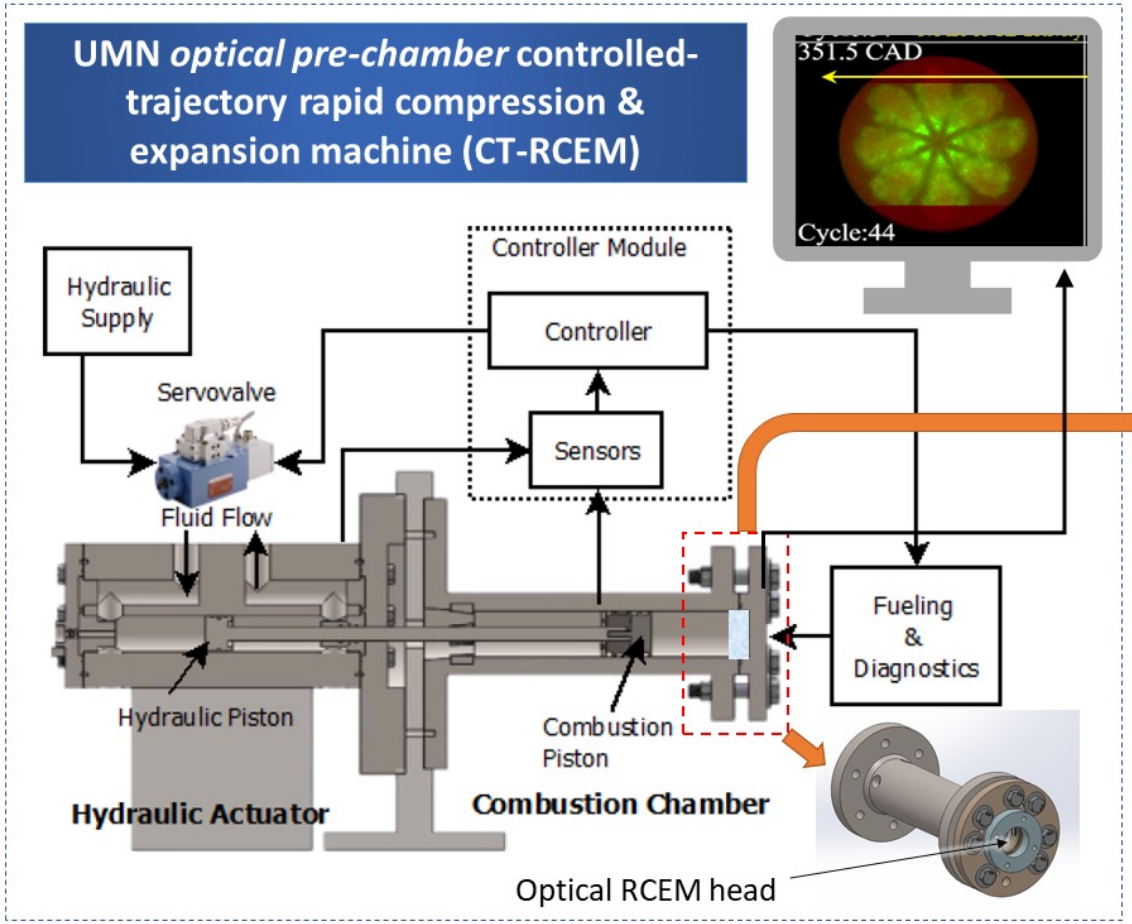
Cummins CARB certified ISB6.7N turbocharged natural gas engine

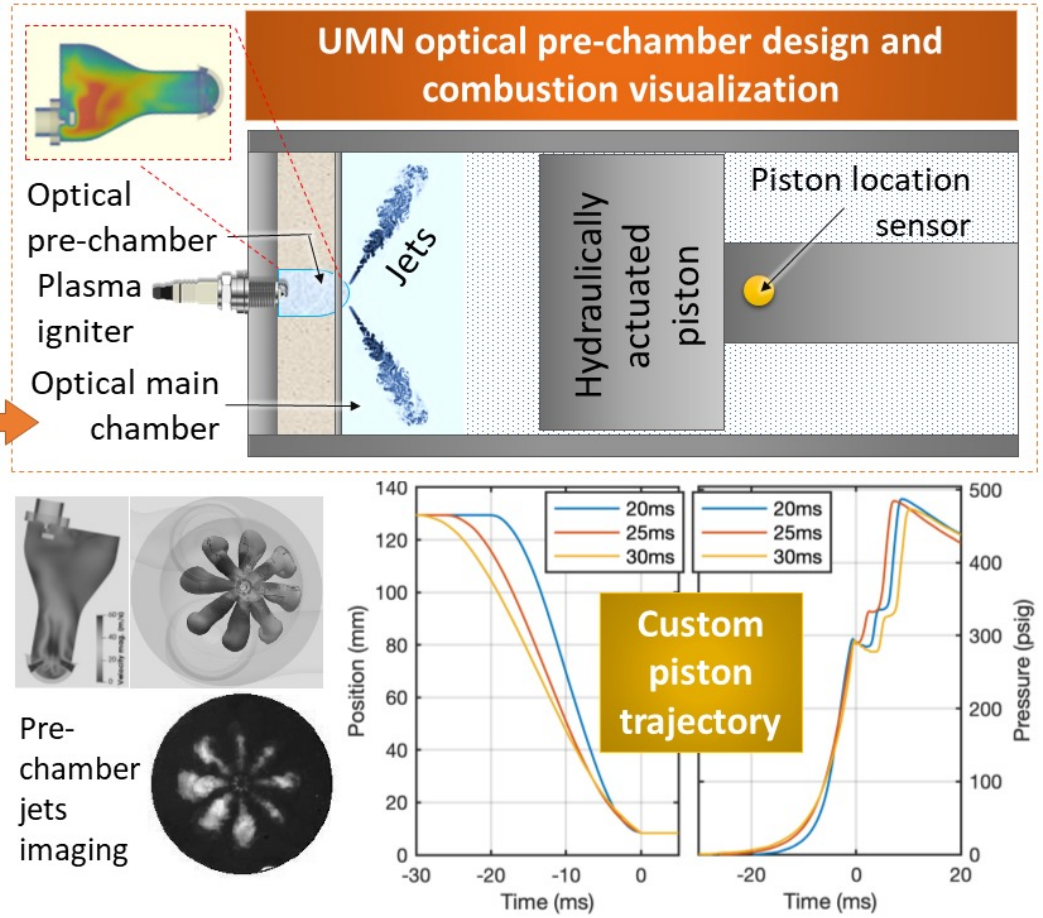




Approach

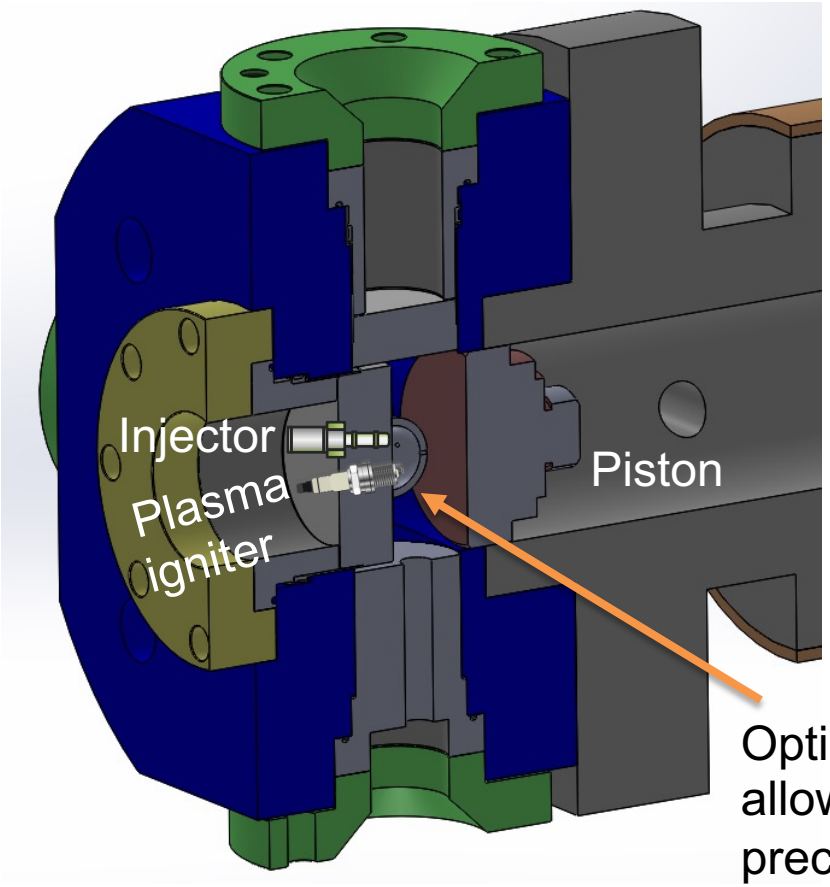
- Optical pre-chamber system for controlled trajectory rapid compression and expansion machine (RCEM)
- Precise control of piston trajectory, allowing accurate reproduction of in-cylinder thermodynamic conditions and associated turbulence and temperature field in the pre-chamber



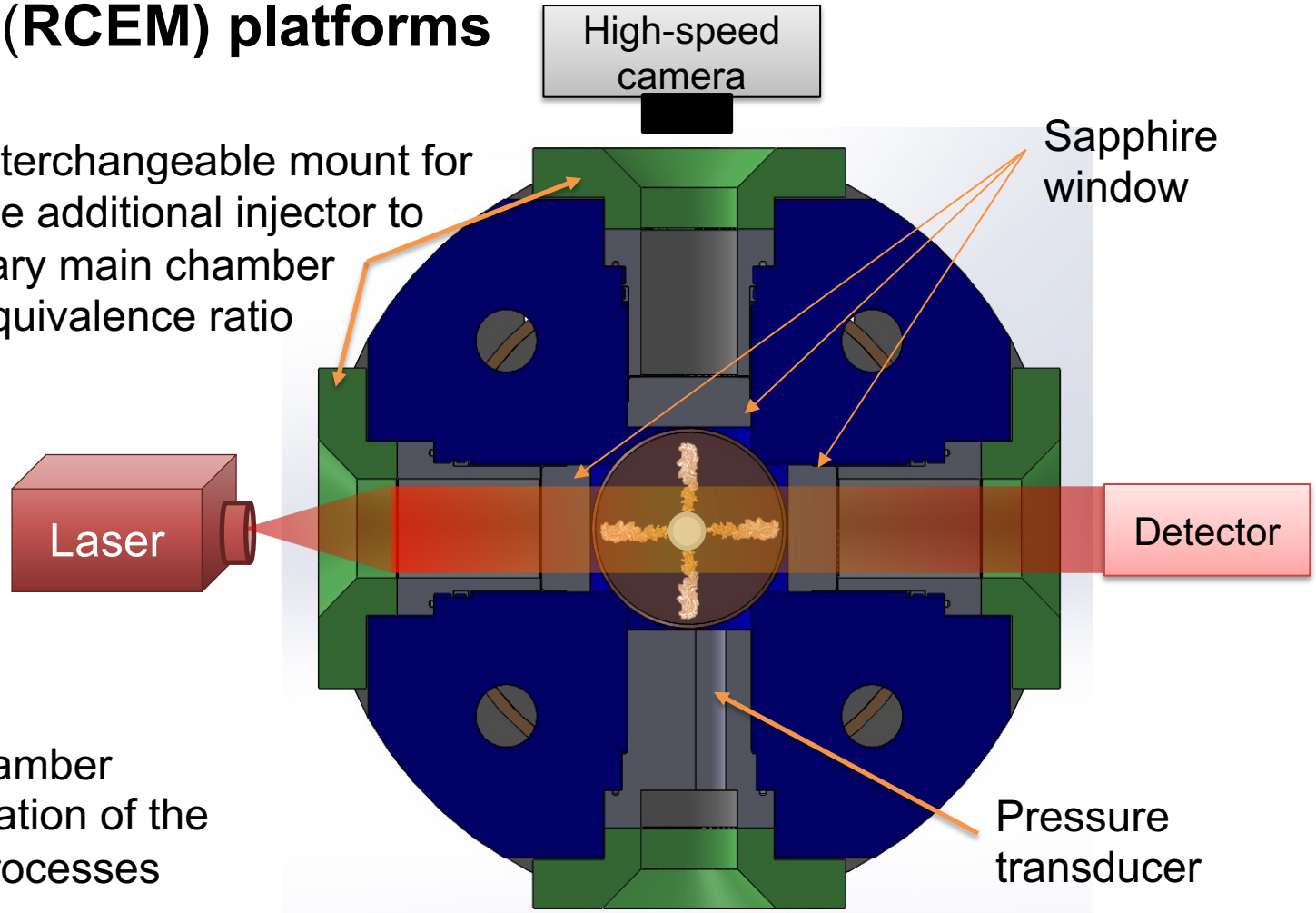


Technical Accomplishments

Task 1.2 – Prepare optical engine and Rapid Compression and Expansion Machine (RCEM) platforms



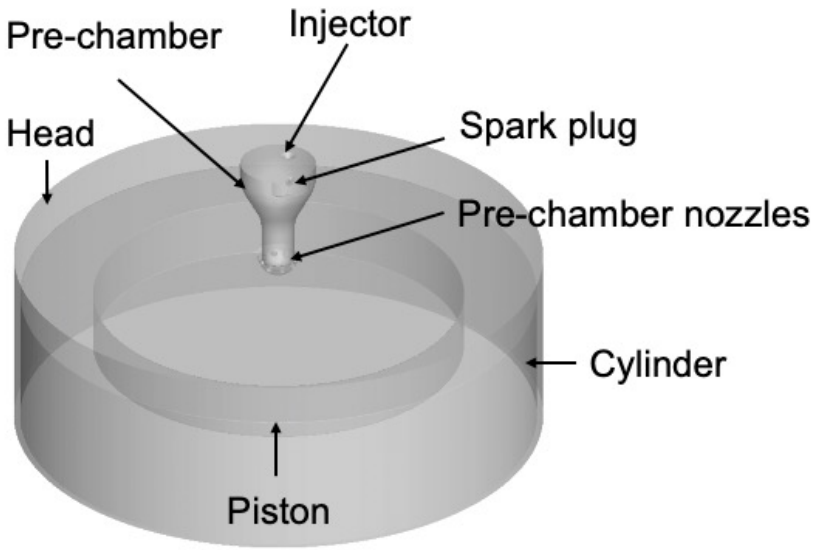
Optical pre-chamber allows visualization of the prechamber processes



Technical Accomplishments

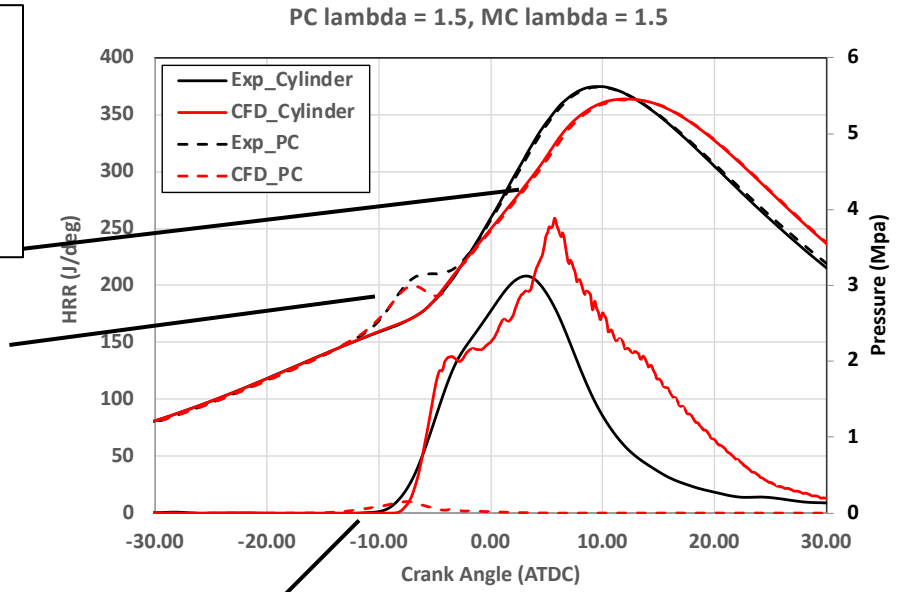
Task 1.3 – Develop, validate, integrate and determine baseline Computational Fluid Dynamics (CFD) model

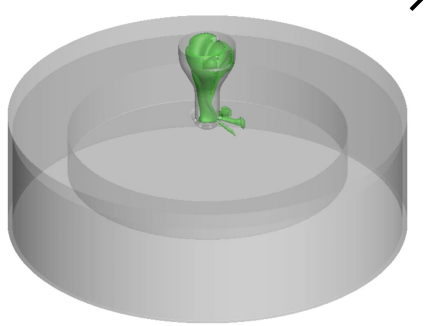
Initial model results for Sandia single cylinder engine with spark plug pre-chamber



Preliminary results are promising, model predicts slower combustion in main chamber

Pre-chamber pressure spike and its transition to main chamber is predicted reasonably well





Asymmetric emergence of jet flames found in model

Response to Previous Comments

This is the first year the project has been presented

Partnerships/Collaborations

Collaborators

Sandia National Laboratories

- Heavy-duty, optical single cylinder experiments
- Plasma-assisted prechamber research and development
- Investigation of advanced combustion modes using plasma-assisted pre-chamber

Carnegie Mellon University, Pittsburgh Pennsylvania 1900

- Computational fluid dynamics (CFD) simulations of plasma-assisted prechamber
- RCEM, optical single cylinder and multi-cylinder simulations

External Partners

Cummins

- Quoted new Cummins B6.7N engine with aftertreatment for use in the project
- Technical support for multi-cylinder engine dynamometer setup and experiments

Remaining Challenges and Barriers

- Design of optical pre-chamber design for RCEM and single cylinder engine experiments
- RCEM modifications and control system robustness
- Sourcing of plasma ignition power supply from a chosen vendor
- Securing validation data for CFD models

Proposed Future Research

To be completed in FY22 and (Q1-2) FY23:

- Develop plasma-assisted pre-chamber and conduct baseline experiments
- Prepare optical engine and RCEM for integration of optical pre-chamber
- Conduct optical experiments on both single cylinder engine and RCEM
- Develop, validate, integrate, and determine baseline CFD model
- Procure and set up multi-cylinder metal engine

Summary

- Project started as of March 1, 2022
- Work has been started on plasma-assisted prechamber design
- Modifications of RCEM instrument underway
- CFD models of single cylinder engine and RCEM in progress with initial comparisons to existing data complete
- Multi-cylinder engine (Cummins B6.7N) sourced and collaboration with Cummins established

Thank You

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